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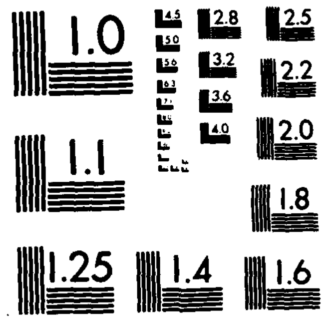

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POST-MIOCENE CAYMAN TROUGH EVOLUTION:

A SPECULATIVE MODEL

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POST-MIOCENE CAYMAN TROUGH EVOLUTION: A SPECULATIVE MODEL

ABSTRACT

The Cayman Trough exhibits cross-trough lineations, which we interpret as crustal fabric formed parallel to the spreading center at the time of crustal generation. Alignment and variations of the spreading fabric are roughly symmetrically distributed about the Mid-Cayman Spreading Center as are variations in the cross-trough width of the Cayman Trough. These suggest to us a simple, eight-stage model of stepwise-varying spreading directions and rates. This model assumes: 1) tectonic spreading fabric is perpendicular to spreading direction, 2) cross-trough extension both widens the trough and lengthens the spreading center, and 3) cross-trough compression narrows the trough but does not shorten the spreading center. Combining the spreading fabric lineation data with these assumptions, we predict a cross-trough width variation that is essentially that of the Cayman. Similar variations in spreading direction should be evidenced elsewhere on the plate boundary if the variations we observe do, in fact, record the history of changes in relative motion between the North American and Caribbean plates.

INTRODUCTION

The Cayman Trough, roughly 100 km wide by 1200 km long, was formed by creation of relatively normal oceanic crust between plates of anomalously thick and buoyant Caribbean sea-floor crust (Holcombe et al., 1973; Burke et al., 1978). In plate tectonic terms, the Cayman Trough is primarily a long transform boundary offset by the Mid-Cayman Spreading Center. Such a transform-dominated boundary is very sensitive to minor changes in the direction of relative motion; small changes may

result in a component of closing (transpression) or opening (transtension) on the transform faults.

This paper will use the physiography of the Cayman Trough to develop a model of relative motion since 15 m.y.B.P. Such a model, inferred from and consistent with the bathymetry and physiography of the trough, will in turn have implications for other parts of the North American-Caribbean plate boundary, provided that the relative motion described by the model is that of the plate as a whole and not second-order resultants of motion within the plate boundary zone.

This initial use of spreading fabric as a predictor of relative motion is, by nature, speculative and approximate. We have simplified the continuous variation in relative motion to a stepwise-varying model. Despite these simplifications our analysis highlights significant variations in direction of relative motion undetected by previous conventional approaches.

THEORY

When oceanic crust is generated at a spreading center, it is imparted with a fabric consisting of faults paralleling the spreading center. The morphology of this fabric is a series of elongate ridges and troughs paralleling the spreading center. The character of spreading fabric varies with spreading rate as does the morphology; slow-spreading ridges such as the Mid-Cayman Spreading Center are characterized by a central rift, rough topography, and faults widely spaced in the spreading direction.

Tectonic spreading fabric essentially parallels the orientation of the spreading center. Analysis of the orientation of spreading centers with respect to spreading directions suggests a distribution more peaked than normal; that is, the assumption of orthogonal spreading is good, though not rigorous (Sharman, et al., 1981). We assume that the mean orientation of spreading fabric in the Cayman Trough is a reasonable estimator of the direction of relative motion between two plates.

Transform fault boundaries, sensu strictu, must be exactly parallel to relative motion, thus lie along small circles about the pole of relative motion. In reality, transform fault boundaries are frequently given to small components of compression or extension, resulting in "compressive" or "leaky" transform faults. In the Cayman Trough, deviation in either sense from pure transcurrent motion will produce deformation along the active plate boundaries. Transtension will cause progressive widening of the trough, with extension along the transform boundaries and concomitant lengthening of the spreading center. Transpression, on the other hand, would cause compressional deformation along the walls of the trough, probably focused on the active plate boundaries, the transform faults. While this should narrow the trough, implications for the length of the spreading center are somewhat more moot in light of Cayman Trough geomorphology. Theoretical considerations would suggest that the spreading center is shortened during periods of transpression by the overriding adjacent plate. However, the progressive widening of the spreading center region of the Cayman Trough relative to the older flanks suggest the contrary: the spreading center seems to maintain its length, even under transpressive plate motion.

DATA

The input to the model is the morphology of the Cayman Trough. The primary data set is a precision geophysical survey by the Naval Oceanographic Office (USNS Wilkes), run as five parallel lines, at 5-10 km spacing, along the length of the Cayman Trough. The data are complemented in the area of the Mid-Cayman Spreading Center by the U.S. Navy-Woods Hole Oceanographic Institution multibeam bathymetric survey (CAYTROUGH, 1979) and supplemented elsewhere in the trough by a general collection of available geophysical lines across the area. Track control for the non-multibeam data is shown in Case and Holcombe (1980).

The precision of the tectonic fabric description varies from very high in and near the axial rift to qualitative at the fringes of the study area. For the area included within the five section lines, trends are generally reliable for high-relief features and are interpretative in varying degrees for smaller features. Bathymetry, based on substantially more track control, was locally helpful in determining trends.

The observations of the trough width are based primarily on the general geophysical lines that cross the trough with a standard navigational precision of ± 2 km. The magnetic anomalies from one of the five E-W NAVOCEANO lines, analyzed and inverted by Macdonald and Holcombe (1978), suggest that the Cayman Trough has been spreading at 40 mm/year from roughly 10 to 2 m.y.B.P. and at 20 mm/yr since 2 m.y.B.P. These are the temporal constraints on any proposed model for the evolution of the Cayman Trough.

A summary of the structural trends in the Cayman Trough area was abstracted from the bathymetry and physiography, and from the structural fabric of Case and Holcombe (1980) (Fig. 1). We feel that the north/south-striking, transverse, ridge structure within the axial third of the trough corresponds to tectonic spreading fabric; the two outer thirds of these ridge structures are clearly distorted by the shear regime of the adjacent transform faults and fracture zones. The discrete measurements of fabric trends summarized in Table 1, and used for model computation, represent this central part of the trough.

The orientations of these structures were compared with that of a small circle about the Minster and Jordan (1979) North American-Caribbean pole of relative motion (34°S, 70°W), clustered into symmetric groups, and averaged (Table 1) to establish a chronology of spreading episodes. Time intervals were assigned to the trend groups (Table 2) according to the spreading rates reported by Macdonald and Holcombe (1978).

Since we estimate the spreading direction from the mean trend of the fabric, the scatter of the data can be compensated with reasonable sample sizes. The standard errors of the mean for the cluster sizes used in this model are 1° to 2° (except for trend C, interpreted as a single fracture zone). The smallest change in mean trend between clusters is 12°; our contention is that the changes in spreading fabric orientation are significant.

Width of the central part of the Cayman Trough decreases symmetrically with respect to the spreading center (Fig. 1). Salients in the south wall impinge upon the trough at about equal distances, 125-150 km, east and west of the active rift. Jamaica lies on the eastern salient. Swan Island lies on the western salient. Width of the trough floor decreases by about 40%, from approximately 115 km at the axis to approximately 75 km at these "choke points" opposite Swan Island and Jamaica. Analogous impingements on the north walls of the trough are less distinct.

MODEL

Three basic rules are employed to generate the model. First, relative motion (spreading) was assumed to be perpendicular to the mean spreading fabric orientation. Second, during periods of transpression, there was a narrowing of the trough, with deformation or overriding, along the active transforms, while the spreading center maintained its length. Third, during periods of transtension, there was a general widening of the trough with extension along the active transforms as well as lengthening of the spreading center.

The inputs to the model were: 1) the lineation trends of the physiography (Fig. 1) defining specific episodes of symmetric spreading varying stepwise in direction of relative motion, and 2) the spreading history of Macdonald and Holcombe (1978) defining the timing and length of the episodes of various spreading directions (Table 2).

The test of the model's appropriateness is the reproduction of the observed patterns of physiography in the Cayman Trough, the cross-trough width variations, and the correspondence between them.

The model for the opening of the Cayman Trough during the last 15 million years has been resolved into 8 episodes of different spreading rates and directions (Table 1, Table 2, Fig. 2). Prior to 15 m.y.B.P., we arbitrarily assume pure transcurrent opening. Starting width of the trough, 40.1 km at 15 m.y.B.P. (Fig. 2 (1)), is obtained by taking the present axial width of the trough (115 km), and then computing a starting width by running the model in reverse. From 15 to 11 m.y.B.P. we assume a 40 mm/yr spreading rate and approximately 14° transtensional relative motion, lengthening the trough by 160 km and widening it by approximately 40 km (Fig. 2 (2)). During the third episode, from 11 to 8.5 m.y.B.P., motion changed to an approximate 1° transtensional direction, lengthening the trough by 100 km and widening it by approximately 2 km (Fig. 2 (3)).

This was followed by a 1 m.y. period of approximately 23° transpressive motion, from 8.5 to 7.5 m.y.B.P., which narrowed the width of the trough (except near the spreading center) by approximately 17 km and lengthened it by 40 km (Fig. 2 (4)). In our analysis of symmetrical grouping of trends, the overall symmetry is enhanced if there is a spreading center jump defined at 7.5 m.y.B.P. with the effect of isolating crust formed from 8.5 to 7.5 m.y.B.P. on the western limb of the trough. The relative motion during this 1 m.y. period prior to the jump is defined by the linear trend "C" (the trend of "C" is relatively well established by geophysical lines).

From 7.5 to 5.0 m.y.B.P. the trough underwent approximately 14° transtension, widening the trough by approximately 25 km and lengthening it by 100 km (Fig. 2 (5)). The sixth episode, from 5.0 to 3.5 m.y.B.P., was approximately 12° transpression, which narrowed the trough by approximately 13 km and lengthened it by 60 km (Fig. 2

(6)). During the seventh episode a 40 mm/yr spreading rate, with an approximate 6° transtensional motion from 3.5 to 2.0 m.y.B.P., added 60 km to the length of the trough and approximately 6 km to the width (Fig. 2 (7)). The spreading rate then slowed to 20 mm/yr and continued from 2.0 to 1.0 m.y.B.P. with an approximate 6° transtensional motion, lengthening the Cayman by 20 km and widening it by approximately 2 km (Fig. 2 (7)). The final episode in this model, from 1.0 m.y.B.P. to present, is approximately a 7° transpressional motion, adding 20 km to the length of the Cayman Trough and diminishing its width by approximately 2 km (Fig. 2 (8)). The end result of this model is 560 km of length added to the Cayman Trough since 15 m.y.B.P., a width of 82.7 km at points about 280 km from the present spreading center, on 15-million-year-old crust, and a width of 115 km at the present spreading center. Compare the model results, Figure 2 (8) and table 2, with the structural trends of the Cayman Trough, Figure 1, and the measured widths.

Because of evidence of south-wall transcurrent movement (Sykes, et al., 1982) and the existence of the Jamaican salient in the wall, a subjective feature was incorporated into our model. During episode 4 (Fig. 2 (4)), the approximately 17 km reduction in width was accommodated along both walls of the trough in the eastern sector. Later, during episodes 7 and 8, the south wall, eastern sector, becomes the site of active transcurrent movement and possible development of a small, "pull-apart" basin.

DISCUSSION AND CONCLUSIONS

The rigorous aspect of the model is the delineation of spreading periods on the basis of parallel physiography. Inherent in this is the sole assumption that the physiography is a reflection of the processes at the spreading center and that the spreading center undergoes temporal variations in orientation. The delineation of spreading periods is subject only to statistical uncertainties in the analysis of the

data and is not dependent on assumptions of symmetrical or orthogonal spreading. The fact that this analysis suggests the existence of a plate boundary reorganization (the jump of the spreading center between episodes 4 and 5 at approximately 7.5 m.y.B.P.) gives testimony to the method's potential and yields a testable hypothesis.

There are two main inferred aspects of the model. The first is the inferred width of the trough, based on the assumption that the spreading center and trough widen under transtension, but only the trough narrows under transpression. This, in turn, implies a monotonic lengthening of the spreading center. The important point is the consistency of the observed variations in the width of the Cayman Trough, along its length, with: 1) variations in spreading directions inferred from the physiography, 2) the episodes of transtension and transpression implied by those variations (Table 2), and 3) our assumptions regarding the changes in width of the trough and length of the spreading center.

The second main inferred aspect of the model is those variations in spreading direction. The inference is based on the assumption of orthogonal spreading, and that the physiography reasonably describes the orientation of the spreading center. The importance of this aspect is the possibility of high resolution indication of North American-Caribbean plate motion for the last 15 million years.

To the degree that we are modeling the effects of overall North American-Caribbean relative plate motion, these implications are testable. The proposed variations would also occur on other parts of the North American-Caribbean plate boundary. Specifically, there is accumulating evidence that the faults and geology of the Central American region of the plate boundary bear evidence of similar shifts in relative motion (Burkart, 1983).

The Cayman Trough provides us with a record of relative plate motions over at least the last 15 million years. The record is in the form of tectonic spreading fabric, well developed in the Cayman Trough because of the slow spreading rates and

the medium-to-slow sedimentation rates, as contrasted with other transform-dominated plate boundaries such as the Gulf of California or the Andaman Sea. We model the history of spreading as eight discrete stepwise-varying episodes of relative motion. Confirmation of this model is found in its ability to reproduce a reasonable facsimile of Cayman Trough geomorphology and to show a correspondence with the variations in the cross-trough width, under the assumption that transtension and transpression widen and narrow the trough, but only transtension changes the cross-trough length of the spreading center, making it longer. This model implies an initial width of the Cayman Trough of approximately 40 km at 15 m.y.B.P. and a specific series of relative motions from 15 m.y.B.P. to present. The model is self-consistent and has implications for variations in relative motion between the North American and Caribbean plates. Evidence for similar variations should be recorded in the geology elsewhere on the North American-Caribbean plate boundary.

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FIGURE CAPTIONS

1. Sketch map of structural trends and tectonic spreading fabric, Cayman Trough area. Solid lines represent structural highs. Hachured lines represent faults, with open hachuring facing downthrown side. Dashed lines trace deep axes of fracture zones, rift valley, and a few large submarine canyons. Heavy lines denote structural relief generally in excess of 1 s two-way travel time, equivalent to about 0.8-1 km. Heavy line paralleling long axis of Cayman Trough is trace of small circle about Caribbean-North American pole of relative motion derived by Minster and Jordan (1978). Letters indicate ridge trend groups as listed in Tables 1 and 2. Alternate groups are shaded.

2. Model depicting evolution of Cayman Trough since late Miocene time (0-15 m.y.B.P.). Double lines denote position and orientation of active spreading center. Half arrows along active transforms denote position and sense of motion. Thrust fault symbol indicates zones of net compression. Full arrows illustrate overall relative plate motion. Sense and timing of relative motion is derived from trends of tectonic spreading fabric as summarized in Tables 1 and 2. Lines parallel to spreading center are crustal formation isochrons, spaced at 0.5 m.y. intervals.

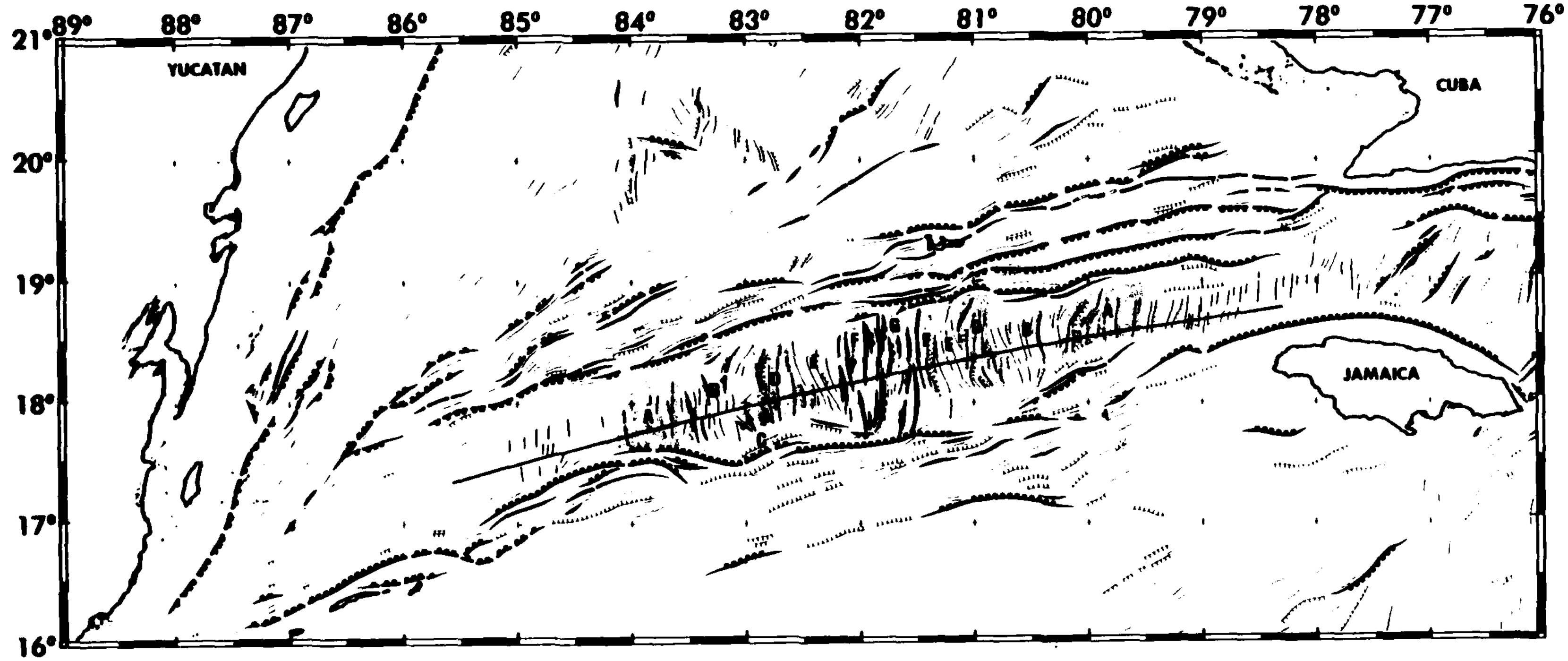
TABLE 1. ORIENTATION OF CLUSTERED TIME-TREND GROUPS OF TECTONIC SPREADING FABRIC

Ridge Trend Group	Number of Trend Measurements	Mean Angle of Intersection (°)	Variation From Normal (+Extensional) (°)	Standard Error of the Mean (°)
A	15	76.1	+13.9	1.0
B	16	89.4	+ 0.6	1.8
C	1	113.0	-23.0	-
D	11	75.8	+14.2	2.1
E	11	102.2	-12.2	0.8
F	20	84.4	+ 5.6	0.9
G	4	96.6	- 6.6	2.0

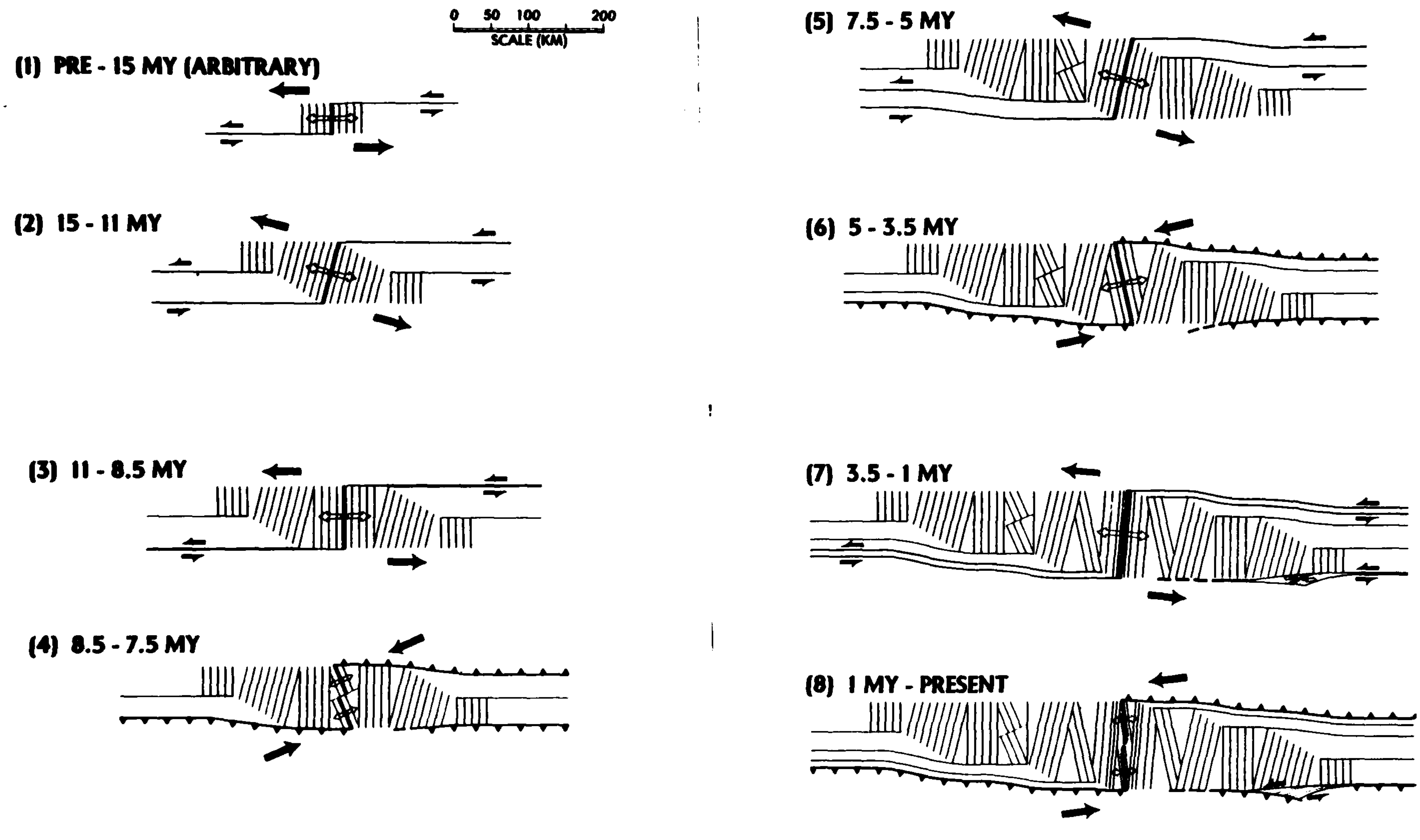
TABLE 2. EIGHT-STEP MODEL FOR CAYMAN TROUGH RELATIVE MOTION

Ridge Trend Group	Time Interval (m.y.B.P.)	Direction of Spreading (+ Transtension)	Opening Along Trough (km)	Opening Across Trough (km)	Starting Axial Trough Width (km)	Starting Trough Width at Choke Point (km)
A	15-11	+14	160	+39.9	40.1	40.1
B	11-8.5	+ 1	100	+ 1.7	80.0	80.0
C	8.5-7.5	-23	40	-17.0	81.7	81.7
D	7.5-5.0	+14	100	+24.9	81.7	64.7
E	5.0-3.5	-12	60	-12.8	106.6	89.6
F	3.5-1.0	+ 6	80	8.4	106.6	76.8
G	1.0-Present	- 7	20	-2.5	115.0	85.2
Present					115.0	82.7
Total	15-0		560			

Measured width at rift axis = 115 km; measured width at east choke point = 82 km; measured width at west choke point = 69 km.



Holcombe and Sharman, Figure 1



Holcombe and Sharman, Figure 2

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